Research Article

Design of Synchronous SEPIC DC-DC Converter of a Stand Alone Photovoltaic System

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Abstract

A synchronous single ended primary inductance DC-DC SEPIC converter is designed and simulated within a PV standalone system. This converter has high efficiency of energy transfer from the generator to load compared to the conventional converters. The diode in the converter is replaced by a PWM controlled switch to make the operating better by avoiding the discontinuous conduction mode and saving diode's inverse voltage. Fuzzy Logic Controller (FLC) is used to extract maximum output power of the PV system. PV energy is the most essential energy resources since it is pollution free, clean and endless. The FLC proposed scheme is interface to generate the PWM (Pulse Width Modulation) for the SEPIC controller for maximum power point tracking operation. FLC is used for more efficient performance under the variation in different atmosphere.

Keywords: Photovoltaic module; Single-ended primary-inductance converter; DC-DC converter; Pulse Width Modulation; Fuzzy logic controller; Efficiency.

Introduction

The renewable energy resources are becoming a boon to the developing world where the necessity of electrical energy is increasing day by day. There are many types of renewable energy resources among them the solar energy is the superlative. Though Photovoltaic (PV) cell has some limitations of high capitation cost, lower conversion efficiency, partial shading and seasonal energy production, it has seized the attention of many researchers because of its special virtues [1].

Natural energy sources, as oil, natural gas, coal, and nuclear are the most used in the world but they are finite and produce pollution, the applications of renewable energy sources, for instance, solar, wind, biomass, and tidal power, as a major form of clean technology could be the right solution to solve energy crisis in the recent century. In order to meet ever increasing demand for conventional energy sources, applications with clean renewable energy technologies, such as photovoltaic (PV) energy have been vigorously developed over recent decade.

Nowadays, the world pays growing attention to the renewable energy sources, friendly, clean and practically inexhaustible, and makes efforts to sustain the improvement of the existing conversion technologies and the development of new ones. Solar photovoltaic conversion is based on the photovoltaic effect to transform a part of energy of the sun to electricity. This technology requires little maintenance but it needs a good implementation of the DC-DC or/and DC-AC converters to obtain high efficiencies. There are lots of researches made in the field of photovoltaic conversion and propose new converters, among them a Sliding-Mode Controlled SEPIC converter is designed [2].

The modelling and simulation of closed loop controlled Buck converter for solar installation [3]; other papers deal with DCDC Buck –boost Converter. Solar energy is the easily available resource for electricity generation [4]. Introduces a synchronous sepic converter simulated in MATLAB/Simulink. Therefore maximum power point tracking

controller is required to improve the efficiency of PV panel by ensuring that PV module continuously gives the maximum power irrespective of the changes in weather conditions [5].

PV has become an important source of energy for a wide range of applications. In the present paper three phase line commutated inverter is operating at fixed value of firing angle, SEPIC converter and its closed loop simulation. It consists of a SEPIC converter, an inductor and line commutated inverter. The SEPIC converter is a non-inverting DC-DC converter and can generate voltages either above or below the input. For reducing the complexity of design of the MPPT algorithm, fuzzy logic control (FLC)-based MPPT algorithms have been proposed [6].

Proposed System

Stand Alone System

The stand-alone photovoltaic system requires storage to meet the energy demand during period of low solar irradiance and night time [7]. The DC-DC converters allow the charge current to be reduced continuously in a way that the resulting batteries voltage is maintained constant at a specific value. The system consists of a photovoltaic generator composed by two modules assembled in parallel, a synchronous DC-DC SEPIC converter controlled by PWM technique, and a bank of batteries.

The input quantities acting on the photovoltaic generator are the irradiance and the temperature [8]; the controller parameters are the pulse width modulation (PWM) signals that control the converters switches by varying duty cycle using fuzzy logic controller (FLC) is shown in Fig. 1. A photovoltaic array is made with combined series/parallel combinations of PV solar modules, which are composed of combinations of PV cells usually assembled in series, the PV cell is a device that absorbs light and converts it into electrical energy in the form of direct current thanks to the photovoltaic effect [9]-[10]. The operating of a PV cell can be represented by an equivalent circuit model is shown in Fig. 2.
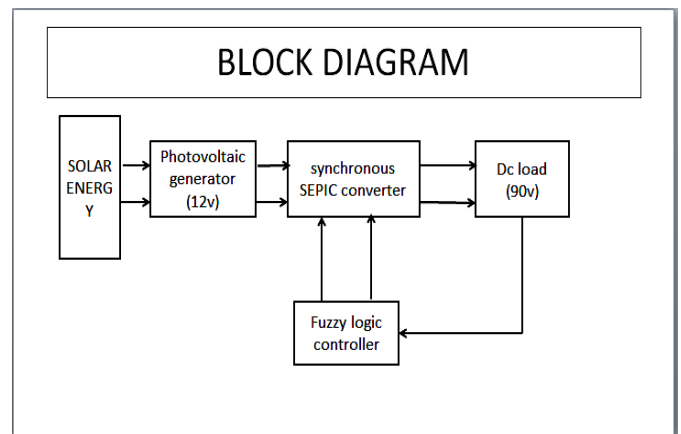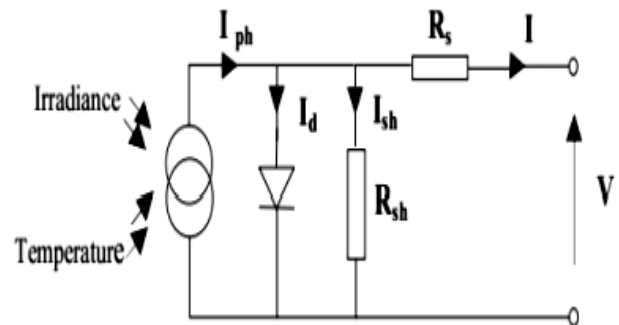

Fig. 1. Block Diagram of Stand Alone System

Fig. 2. Equivalent circuit of photovoltaic cell

The basic equation that describes the I-V curve characteristic of the photovoltaic model in equation 1.

$$I = I_{ph} - I_s \cdot \left[\exp\left(\frac{q(V + R_s I)}{nkT}\right) - 1 \right] - \frac{V + R_s I}{R_{sh}} \quad \text{...(1)}$$

Where:

I - cell current (A).
I_{ph}-light generated current (A).
I_s - diode saturation current (A).
q- Charge of electron = l.6xl0-l9 (Coulomb).
V-cell output voltage (V).
R_s -series resistor (Ω).
K- Boltzmann constant = l.380662 × l0-23 (j/K).
T- Cell temperature (K) & R_{sh}- shunt resistor (Ω).

Synchronous SEPIC DC-DC Converter

A synchronous single ended primary inductance DC-DC SEPIC converter is designed and simulated within a PV standalone system. This converter has high efficiency of energy transfer from the generator to load compared to the conventional converters. The diode in the converter is replaced by a PWM controlled

switch to make the operating better by avoiding the discontinuous conduction mode and saving diode's inverse voltage. Fuzzy Logic Controller (FLC) is used to extract maximum output power of the PV system. PV energy is the most essential energy resources since it is pollution free, clean and endless. The FLC proposed scheme is interface to generate the PWM (Pulse Width Modulation) for the SEPIC controller for maximum power point tracking operation. FLC is used for more efficient performance under the variation in different atmosphere. The single-ended primary-inductance converter (SEPIC) is a step-down/step-up DC-DC converter circuit that provides a constant positive output voltage from a positive input voltage which can be lower or higher than the output. The single ended primary-inductance converter (SEPIC) is a DC-DC converter which will step-up/step-down the input voltage without any polarity reversal. The converter output voltage greater or less than input without polarity reversal useful in so many applications. This type of circuits can be used to maintain output voltage constant. The asynchronous SEPIC converter (Fig. 3) which consists of input capacitor C_{in} an output capacitor C_{out}, coupling capacitor C_c, inductors L1 and L2, a diode and a switch Q1. The below circuit consists of diode so there will be loss of inverse diode voltage.
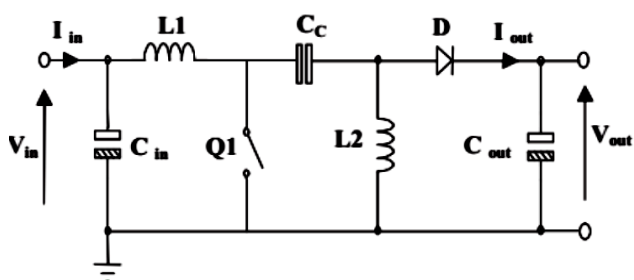

Fig. 3. Asynchronous SEPIC converter

The proposed method diode is replaced by switch Q2 to save the inverse diode voltage and to operate the circuit in continuous conduction mode (Fig. 4). The two switches of both the converters are complementary to each other they are operated by applying pulse width modulation (PWM) signals. There are two operating modes when Q1 is and Q2 is off and when Q2 is ON and Q1 is OFF. ON time of switch will DT and

OFF time of switch is (1-D) T. Where D is the duty cycle of the switch and T is the time period.
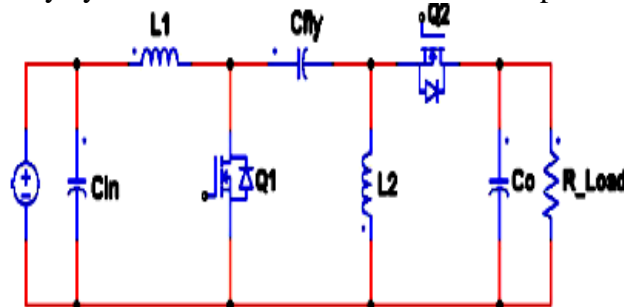

Fig. 4. Equivalent circuit of synchronous SEPIC converter

To make the converter operates in its continuous conduction mode, it must be synchronized. The proposed method is to replace the diode D by another switch Q2 (Fig. 5) and this is to avoid any shift and also to save the inverse diode voltage.
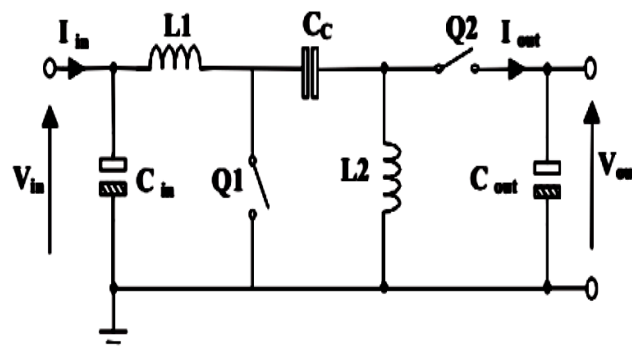

Fig. 5. Synchronous SEPIC converter

Those two switches, Q1 and Q2 are controlled by two complementary PWM signals produced in the driving circuit using a saw tooth generator. In continuous conduction mode, SEPIC converter has two operating modes "Q1 on, Q2 off" and "Q1 off, Q2 on " (Fig. 6).
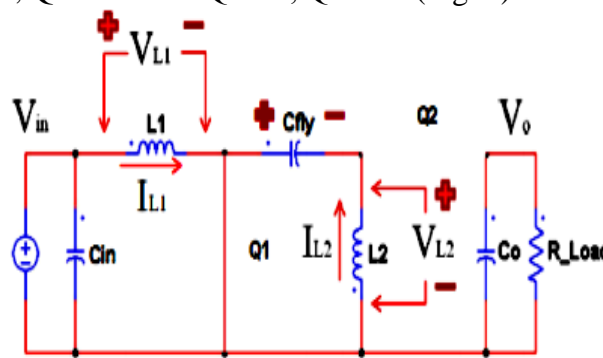

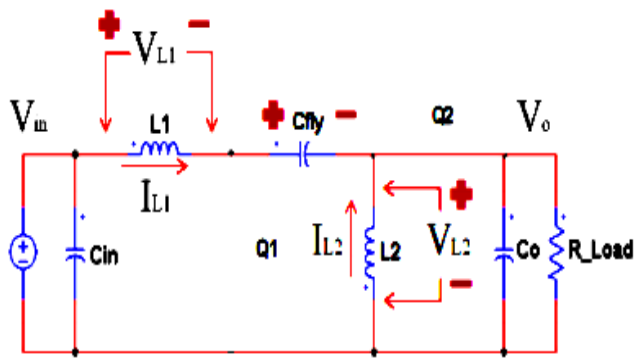Fig. 6. First operating mode "Q1 on, Q2 off" for DT seconds

Fig. 7. Second operating mode "Q1 off, Q2 on "for (1-D) T seconds

The two modes of operation when Q1 is ON and Q2 is OFF and when Q1 is OFF and Q2 is ON. When Q1 is ON and Q2 is OFF the converter Cfly charged to input voltage Vin.

Apply KVL for the loop containing Vin, L1, Cfly and L2 for

$$-V_{in}+V_{L1}+V_{Cfly}-V_{L2}=0$$

Using average of these voltages, -

$$V_{in}+0+V_{Cfly}-0=0,$$
$$V_{Cfly}=Vin$$

The inductor L2 is connected parallel to Cfly so voltage across L2 is also Vin. Inductors L1 and L2 charges from the voltages Vin and Cfly respectively. The Co discharges through output. When Q1 is OFF and Q2 is ON, then what ever the stored energy in L1 is discharged to Cfly, switch Q2 and into Cout and to the load. Voltage Vo will appear across L2 since they are parallel. Capacitors Cfly and Co will recharge and cycle repeats (Fig. 8).
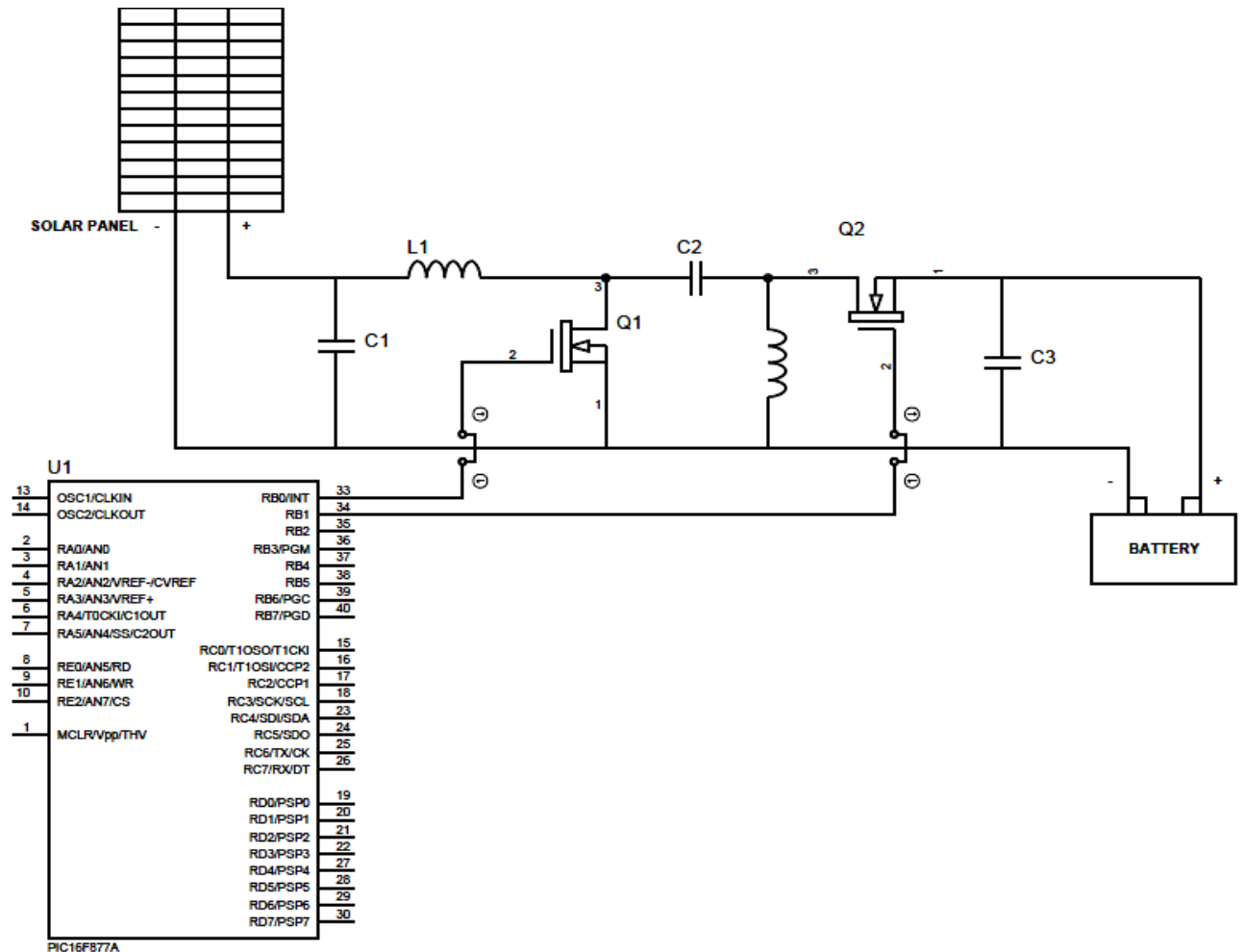

Fig. 8. Circuit diagram of SEPIC converter

Fuzzy Logic Controller (FLC)

Fuzzification, logic judgment, and defuzzification are the three consecutive stages of an FLC. The fundamental structure of a fuzzy

logic controller is shown in Fig. 9. At the stage of fuzzification, the numerical ratio, dP/dV (the change in PV power to the change in PV voltage, DP/DV) is translated into a linguistic variable via membership functions. The numerical offset,

dV is the previous perturbation offset, DV. "dP/dV" and "dV" are two input linguistic variables of the FLC (Fig. 10). At the beginning of every control interval of the FLC, the numerical inputs are translated into logic linguistic elements. According to the membership functions of dP/dV and dV, the input variables can be classified as "Positive Big", "Negative Big", "Positive Small", "Negative Small", "Positive Zero", and "Negative Zero" (Table 1). Different from binary logic controllers, FLCs not only define variables with binary logic values, 0 and 1, but also provide degrees of variables.
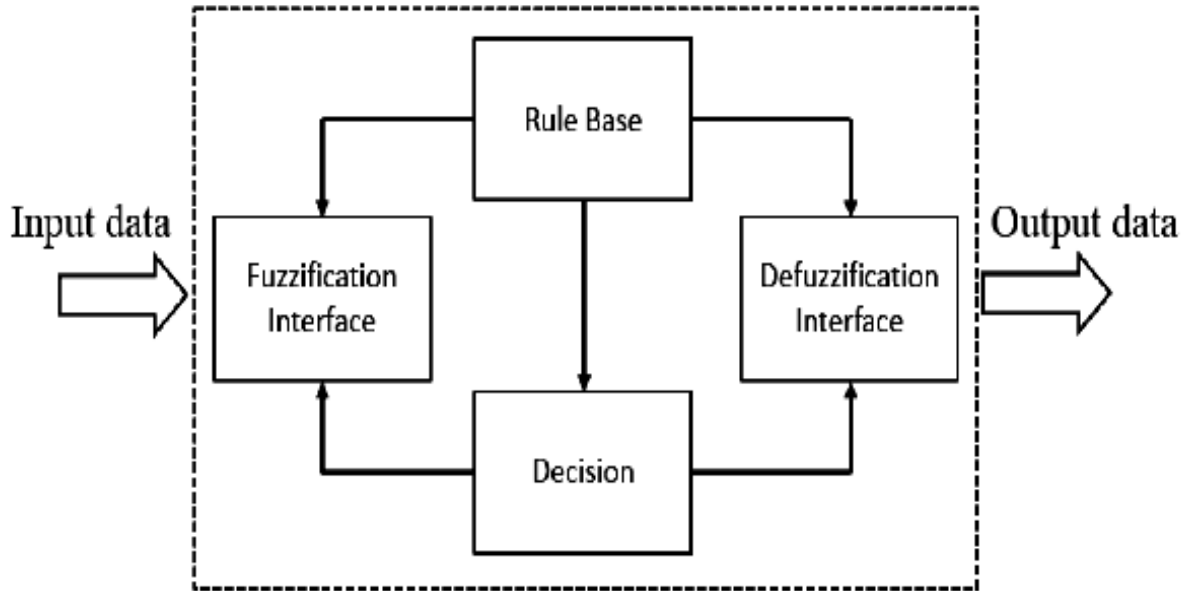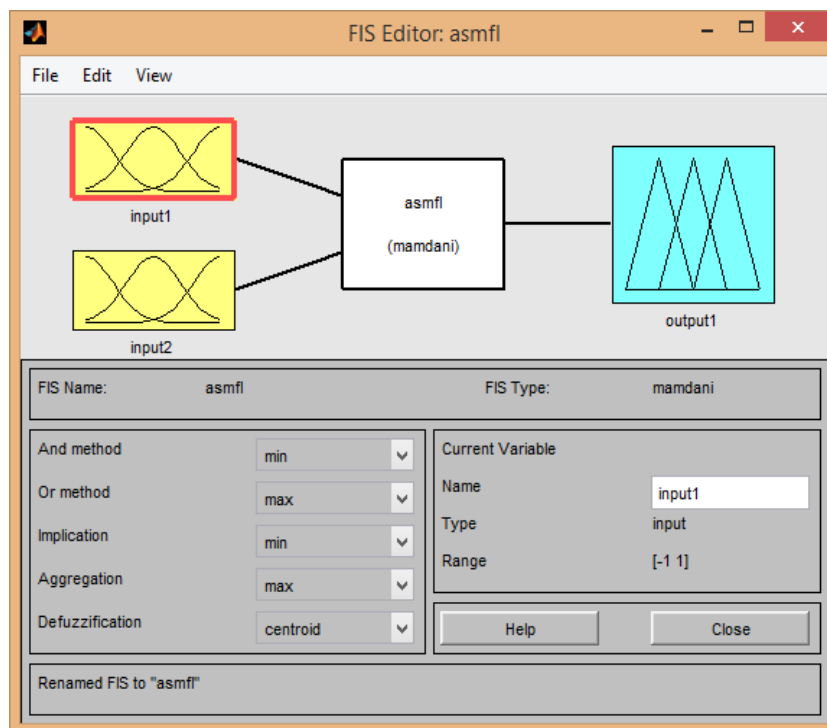

Fig. 9. Structure of Fuzzy Logic Controller

Fig. 10. Fuzzy logic controller

Table 1. Fuzzy Rule-Based Matrix

dV \ dP/dV	NB	NS	NZ	PZ	PS	PB
NB	NZ	NZ	NZ	PZ	PZ	PZ
NS	NZ	NZ	NZ	PZ	PZ	PZ
NZ	NB	NS	NZ	PZ	PZ	PZ
PZ	NZ	NZ	NZ	PZ	PS	PB
PS	NZ	NZ	NZ	PZ	PZ	PZ
PB	NZ	NZ	NZ	PZ	PZ	PZ

Simulation Results

The proposed topology is implemented in Matlab/Simulink (Fig. 11) to validate the converter performance. The input solar irradiation is considered as a constant and continuously varies with time. The converter switching frequency is chosen as 20KHz. Duty cycle of switches is varied from 30% to 70% for buck and boost operations. The output voltage from the PV system V_{in}=44.2V. The simulation of solar panel model is done by Matlab/Simulink is shown in Fig. 12. An input voltage of 44.2V at 25°C (standard test condition) from the PV array (Fig. 13). The desired output voltage of the Synchronous SEPIC converter is 180 V (Fig. 14).

Conclusions

This paper presented the simulation work of a photovoltaic array to grid connected system. A simple open loop scheme employing a SEPIC converter and inverter has been developed for interfacing solar array with the utility grid. Simulation studies have been carried out to get the various parameters of the scheme such as active power and reactive powers. As the inverter is being operated as line commutated, the synchronization of output frequency with grid frequency does not arise. However due to losses in the inductor, the output power fed to the grid is fairly small. The results show that it has many advantages over conventional converters and it is a good choice to be taken in the case of autonomous systems because of its simple operation where it only has two states of operation, so, the discontinuous conduction mode has been avoided and the inverse voltage of the diode is eliminated by replacing it with another switch controlled by PWM. However, the function of this converter maintains its output voltage constant which can improve the efficiency of the photovoltaic system and ensure a good transfer of energy.
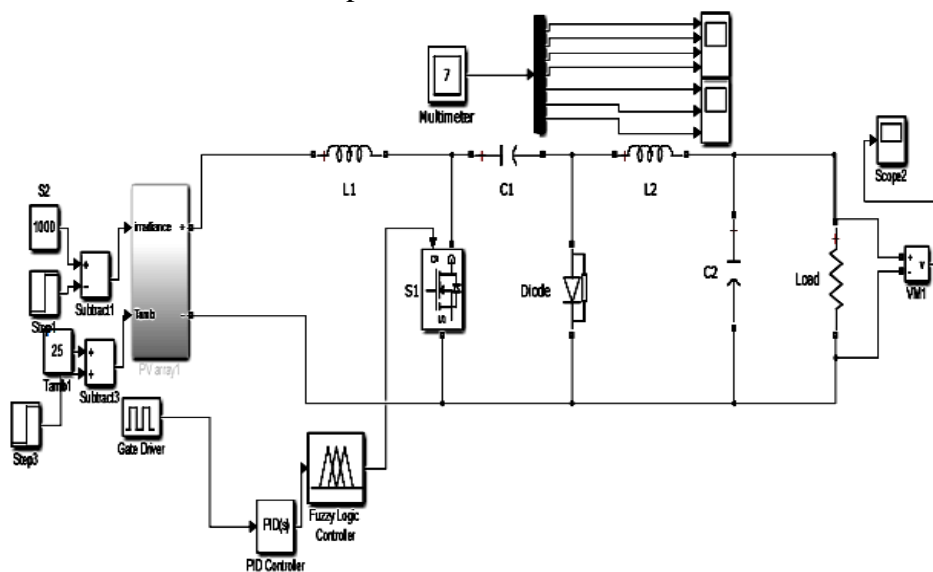

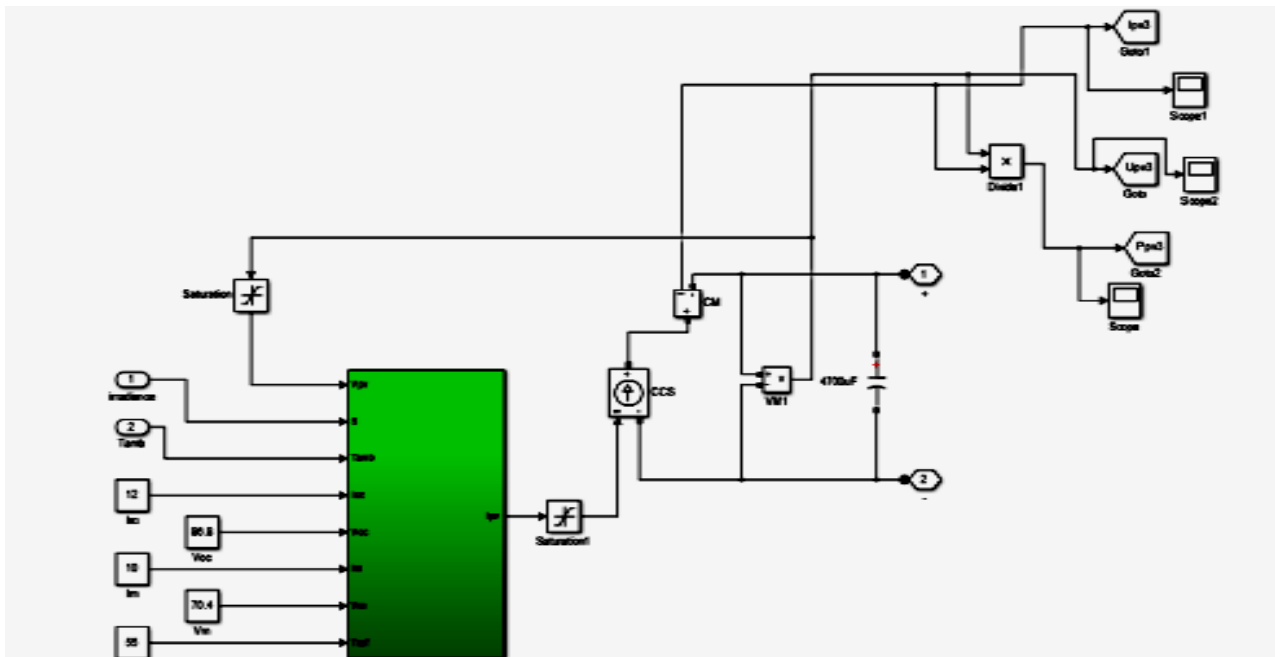Fig. 11. Simulation of Proposed Synchronous SEPIC converter

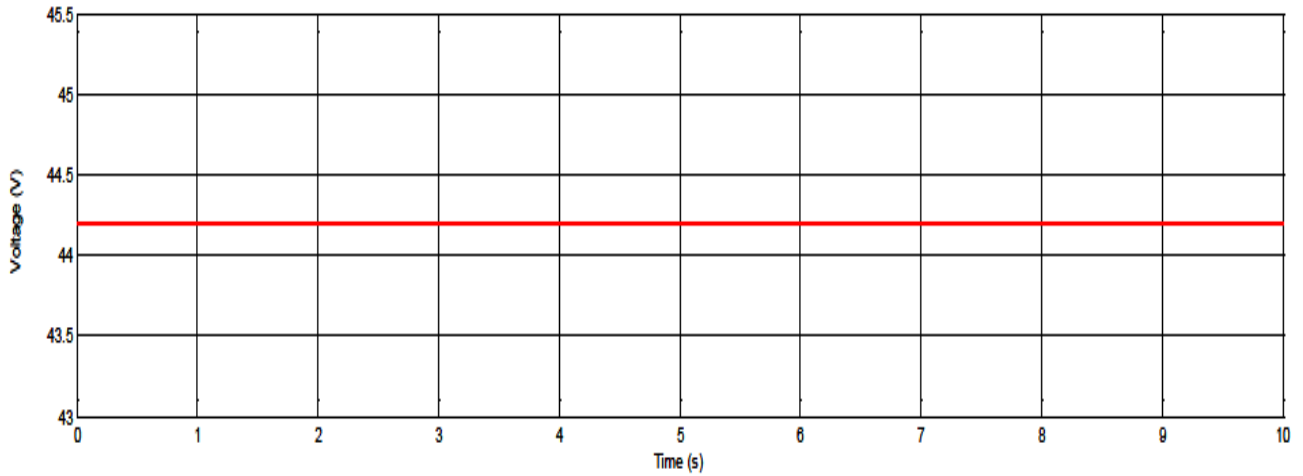　　　　31

Fig.12: Simulation of solar panel model
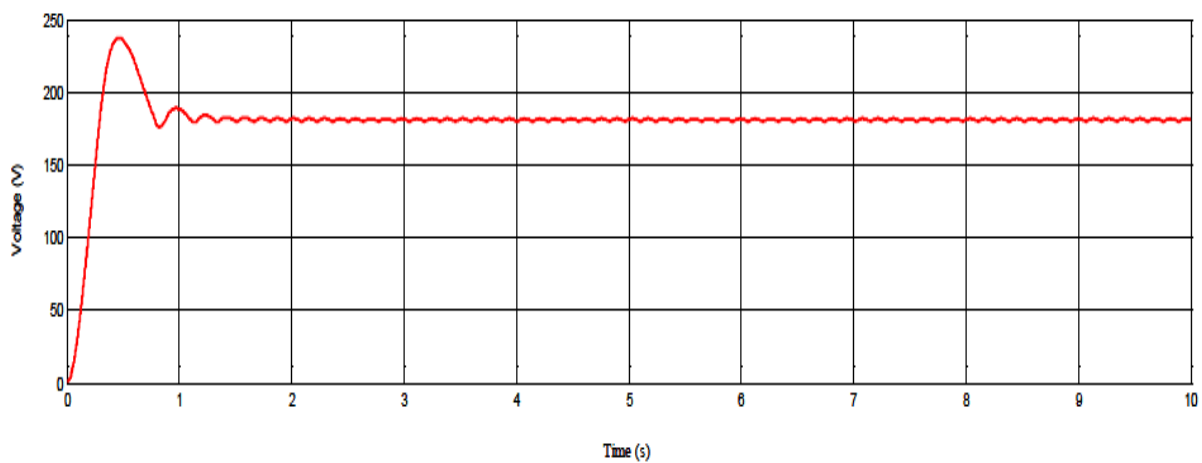

Fig. 13. Output Voltage of PV Array

Fig. 14. Output Voltage of Synchronous SEPIC Converter

Conflict of interest

Authors declare there are no conflicts of interest.

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